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Abstract. We propose the *Navisio* software as a new integrated system to help low vision patients read complex electronic documents (here, PDF files) with more comfort. *Navisio* aims at taking into account main psychophysical results on reading performance of visually impaired patients. To do this, we analyze what are the main factors influencing reading performance, and review some existing reading aid systems, dealing with printed and electronic documents. Then, we show how *Navisio* allows to extend the capabilities of existing reading systems, focusing on the facilitation to navigate in complex documents, and on the highly customizable display. *Navisio* performance was evaluated against a standard CCTV magnifier tool, with 26 low vision patients. Two kinds of texts were proposed (simple and complex documents) elaborated from a standardised text database. Results show a clear advantage of *Navisio* in terms of reading speed and comfort. *Navisio* is intended to evolve: we discuss how it could be extended to any scanned document, thanks to recent computer vision approaches in document layout analysis. Further challenging perspectives are also mentioned.

1 Introduction: About low vision and reading deficiencies

Low vision is defined as a permanent form of visual impairment which cannot be corrected with an optical correction and which leads to the inability to read the newspaper from a conventional viewing distance of 40cm.

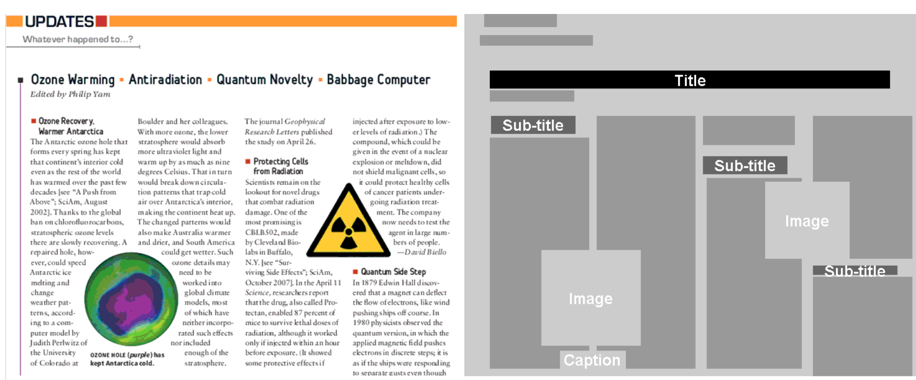
Leading causes of low vision are age-related eye diseases like macular degeneration ($\geq$ 50%), glaucoma, diabetic retinopathy and cataract. They cause a decrease of the visual acuity and dramatically affect everyday life. Most of these diseases induce central field loss (CFL): Patients are blind in their central visual field (this is defined as a scotoma), i.e., they cannot use the fovea, the highest resolution part of the retina to explore visual scenes (see Figure 1). In 2004, the World Health Organization estimated that 124 millions people suffered from low vision in the world, using the visual acuity (ability to recognize small letters) to characterize the low vision impairment. (see Table 1).

Visual Acuity (Snellen scale)	Visual Impairment
$\geq 20/30$	Normal Vision
20/30 to 20/70	Mild Visual Impairment
20/70 to 20/200	Moderate Low Vision
20/200 to 20/500	Severe Low Vision
20/500 to 20/1000	Profound Low Vision
$\leq 20/1000$	Blindness

Table 1. Ranges of visual acuity loss (Source: World Health Organization)

(a) (b) (c)

Fig. 1. Qualitative representation of the perceived image by a patient in front of a zoomed text displayed on a computer screen. (a) Image of a text displayed on a standard video monitor, with (b) the simulated acuity depending on the gaze and eccentricity and (c) with a black area corresponding to an absolute scotoma area. The legible letters correspond to the average visual span [1].



(a) (b)

Fig. 2. Illustration of a complex document layout composed as a set of titles, paragraphs and images.

In most cases, medical treatments can slow down the development of the pathology to blindness. Unfortunately, there is no treatment to recover the damaged part of the eyes in low vision. Visual prosthesis and ophthalmic devices recently made substantial progress, but we are still far from allowing patients to perceive fine details (see [2] for a recent overview). Consequently, patients have to adapt their everyday life activities, and especially reading, which is often declared as the most dramatic loss.

To measure reading performance in low vision patients, the reading speed is the most currently chosen indicator and different calibrated tools allow to characterize precisely the reading deficiency of the patient (see, e.g., the MNREAD test [3]). In normal vision, reading speed increases with character print size until a maximum reading speed is reached [4]. When this maximum reading speed is reached, the corresponding character size is called the critical print size (CPS). The same observation is true for low vision patients [5], but the CPS is higher, and the maximum reading speed is less. So, raising the print size only for low vision readers is not sufficient to recover the "normal vision" maximum reading speed. This is explained by other limiting factors besides visual acuity in low vision reading such as the restriction of the visual field (holes and distorsions in the visual field), lateral masking (also called crowding [6,7]), fixation instability [8] or oculomotor inabilities [9].

The complexity of the document (see, e.g., Figure 2) is also an important limiting factor in low vision reading. The patient has to extract different paragraphs and pictures and to read them in a defined order. Reading speed for these documents is naturally less important.

This paper is organized as follows. Section 2 analyzes what are the main factors influencing the reading performance and presents an overview of some existing reading aid systems, dealing with printed and electronic documents. Section 3 describes the *Navisio* software, which was designed to help low level patients read and navigate in complex electronic documents (here PDF files). Then, we propose in Section 4 a comparative study, obtained with 26 low vision patients, of the performance of *Navisio* against a classical CCTV magnifier. We conclude in Section 5 showing the numerous possible extensions of *Navisio*, including some challenging perspectives.

2 Reading aid systems in low vision

2.1 What are the important features?

Optimal character display As mentioned in the introduction, text must be displayed at a sufficient size to be read with a maximal reading speed. This size can be very high for severe pathologies ($\geq 2°$ visual angle for a mean character high) whereas this CPS is about $0.2°$ for normal vision [4].

Many psychophysical studies showed the interest to improve the legibility of a text to increase reading performance. People with low vision usually read better with white-on-black text [10] and a maximum contrast is necessary for an optimal reading [11]. A strong interpatient variability exists for fonts [12] and for background/foreground colors [13] in reading speed. For a complete review about the legibility of typefaces, see, e.g., [14] and [15] (chapter 4).

Some experiments tried to decrease crowding effect between letters in low vision reading. These studies tried to increase interletter spacing [16], interline spacing [17] or to inverse polarity between each adjacent letter [18]. They showed little (for the interline variation) or no significant gain on the reading speed.

To summarize, an optimal character display is a high luminance contrast display with a magnified print size superior to the CPS. Other display parameters like color or font have to be defined individually for each patient.

Optimal presentation of a text Magnifying a text on a screen implies moving it dynamically because of the "window-size effect": a trade-off between the angular size of characters and the field size.

Automatic scrolling was proved to be the fastest way to read a text on a screen for low vision patients, rather than manual methods using visuomotor combination to scroll text [19]. The automatic drift mode was also the preferred mode in normal and low vision, and no difference was found between horizontal and vertical scroll [20].

With the Rapid Serial Visual Presentation (RSVP), each word is successively displayed on a screen to limit eye movements during reading. Exposure time can be constant, length-word dependant or the patient can decide when to display another word. RSVP reading speed is as fast as with scroll presentation, but users usually don't consider RSVP as pleasant.

The local/global navigation problem A complex page layout (see for example Figure 2) introduces a local/global navigation problem: It is necessary to enlarge one or different local regions of the document to infer the global layout.

2.2 About main existing systems

In this section we give an overview of the main existing systems for accessibility. Table 2 summarizes some of the key features. Note that useful links are available in the electronic version of this document.

Reading aid systems for printed documents: These systems are frequently used by low vision patients who want to read or write. A region of the document is captured by a camera and magnified onto a monitor. One can distinguish two main systems:

- The closed-circuit television (CCTV) magnifiers (such as *Clearview+*): CCTV magnifiers display in real-time the captured image onto a monitor. It is usually possible to maximize the contrast and to select the background and foreground colours. Text can be zoomed up to 60x with a high-quality display. Portative hand-held magnifiers are also proposed. As far as reading

	Clearview+	*myReader2*	*ZoomText*	*Jaws*	*Navisio*
Printed documents	✔	✔	-	-	-
Electronic documents	-	-	✔	✔	✔
Need for dedicated hardware	✔	✔	-	-	-
Audio output	-	-	✔	✔	-
Text reformatting	-	✔	✔	-	✔
Automatic scroll	-	✔	✔	-	✔
Local/Global display	-	-	-	-	✔
Price	$$$	$$$$	$	$$	free

Table 2. Comparison of typical existing systems and *Navisio*. Note that text reformatting is the possibility to change the text display more than with a simple zoom. Concerning the price information, *Navisio* is currently in the process to become an open source software.

is concerned, using a CCTV magnifier requires combining eye movements with manual movements to move the magnifier over the text. Thus, reading with a CCTV magnifier is more difficult than reading a static enhanced text. In particular, there is an important local/global navigation problem with CCTV magnifier because of the difficulty for the patient to know his relative position in a complex document. Jumping to the next line of a text also takes time: from 17% up to 50% of the total reading time is dedicated to the retrace time. For more details on CCTV performance evaluation, we refer to [21,22].

- The *myReader2* tool: *myReader2* is a reformatting system which scans the document, performs text analysis and recognition (which may take several seconds), and displays text in a new format (text parameters, scrolling type). This tool has been tested on low vision patients, and it was compared with CCTV: Its efficiency was proved in terms of reading speed and reading comfort [23]. A special control panel is also proposed to optimize ergonomy. However, as indicated in [24], *myReader2* has some limitations to deal with complex documents.

Reading aid systems for electronic documents: Beside the built-in accessibility features proposed GUI, operating systems, navigation engines or edition softwares (see, e.g., zoom modes by Microsoft, PDF accessibility by Adobe, Firefox accessibility features), there is a wide variety of relevant softwares available. One can distinguish two main systems:

- The ”computer-screen magnifier” aid: Some parts of the screen can be enhanced (see, e.g., *ZoomText* or *Lunar*). The navigation and the selection on the monitor are controlled by an enhanced and slowed cursor moved thanks to keyboard or mouse. The text can be zoomed up to 20x and is displayed with the possibility to customize contrast, colors, and an anti-aliasing function in most of the softwares. Another interesting feature, for example

proposed by *ZoomText* is that subjects can read a selected text in a special environment, so that text is reformatted for easier reading.
- The "screen reader" aid: Thanks to this processing, blind or low vision patients can listen to document files read aloud by synthetic speech (see, e.g., *Jaws*, *Windows-Eyes* or *Vocale Presse* for French press).

Usually, reading aid softwares propose the audio and enhanced functionalities and patients can use both modes.

3 Navisio: enhanced reading and new navigation possibilities

3.1 General description

Navisio is an electronic document magnification software[4]. It was programmed in C++ and it runs on Windows or Linux systems. The goal of *Navisio* is to help low vision patients read simple and complex PDF documents with text and images. To do this, *Navisio* offers new navigation possibilities based on two view modes (see Figure 3): a *document view* and an *enhanced view*. The document view corresponds to the global standart view of the document, and the enhanced view corresponds to a reformatted view of a paragraph (or an image) which has been selected in the document view. The user can easily switch from one view to the other.

3.2 The global document view

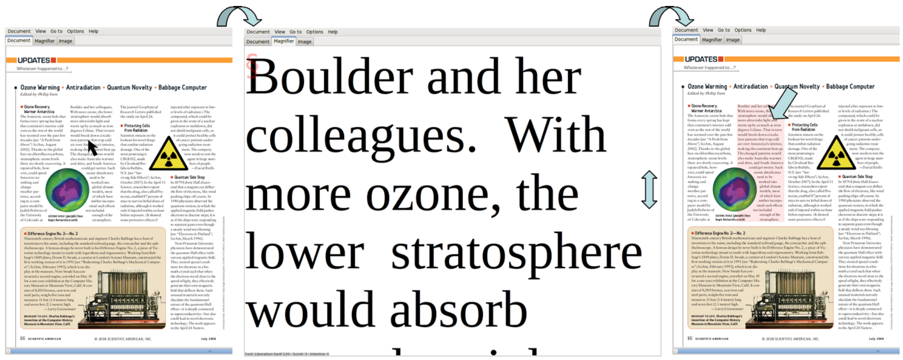
In this mode, the raw document is presented with text paragraphs and images. The user navigates in the document with a cursor (shape and speed of the mouse are adjustable) controlled by the mouse. The user can zoom on the document before selecting a part with the cursor (see Figure 4). Once selected, the part of the document is displayed in the enhanced view (see Section 3.3).

Navisio proposes a color code in the document view: Every paragraph which has been displayed in the enhanced view will be highlighted with a color-code. The color is different if the paragraph was just selected or selected previously (see examples in Figures 3 (c) and 6 (a)). Thanks to this color-code, the patient knows the exact position of the paragraph which was just read and also knows what remains to be read.

3.3 The local enhanced view

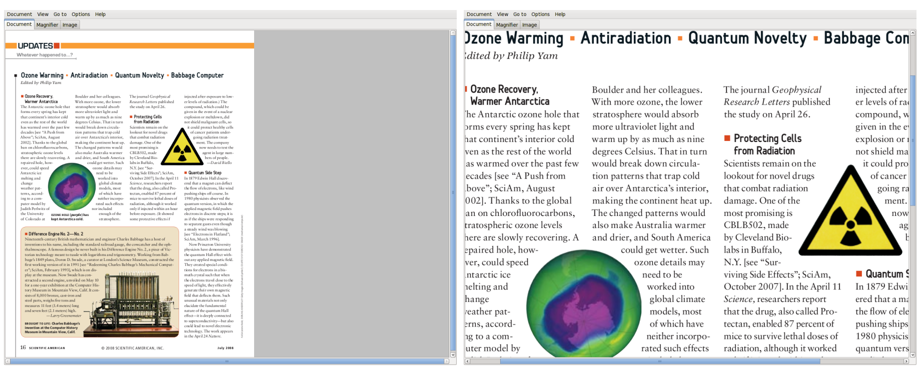
In the enhanced mode (see Figure 5), the user can magnify a selected paragraph with a large panel of reformatting parameters, most of which are related to psychophysics results (see Section 2.1). With customizable shortcuts, the user can

[4] *Navisio* is currently in the process to become an open source software.



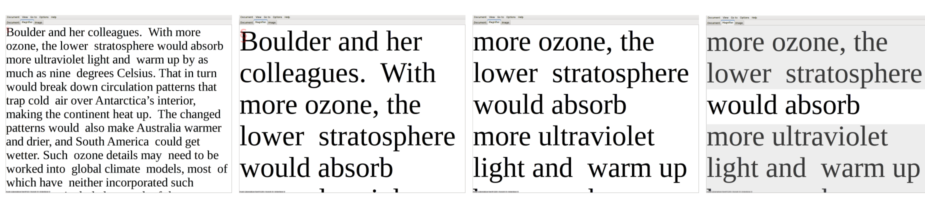
Document view (a) Enhanced view (b) Document view (c)

Fig. 3. Illustration of the navigation between the document view and the enhanced view. (a) The patient selects a paragraph in the document view. (b) This paragraph is displayed on the enhanced view according to patient preferences (see also Figure 5). (c) At any time, the patient can come back to the document view: the paragraphs just read are highlighted (here in red). When other parts of the document were selected before, they are also highlighted in a different color.



(a) (b)

Fig. 4. Example of document view: (a) Once the document is opened, it is shown full page. (b) Then patient can zoom in and move to focus on specific parts.



(a) (b) (c) (d)

Fig. 5. Some features of the enhanced view: (a) Example of an enhanced view. (b) Same paragraph with different display parameters. (c) The patient then reads the text scrolling with the mouse (the scrolling is manual; drift speed can be adjusted). One automatically reads all subsequent paragraphs if some have been found (see Section 3.4). (d) Some enhancements are also possible such as putting more relative contrast to the central line.

easily adjust the display (font, character size, interline size, background and foreground colors, and other enhancements) or select the scrolling type (horizontal or vertical). Note that all this personalized set of parameters can be saved in a configuration file so that several users can use *Navisio* and just need to reload their preferences.

If an image instead of a paragraph is selected, the display is automatically in the maximum resolution (the image can have been reduced in the raw document) and can also be zoomed.

3.4 Document layout analysis with *Navisio*

Navisio integrates a document layout analysis: For example, given a PDF document, each paragraph is segmented based on the PDF file structure, and some relations can be established between paragraphs using simple heuristics. For example, in Figure 2, if one selects the paragraph at the top of a column, then every paragraphs will be displayed sequentially (a symbol indicates the change between two paragraphs).

Of course, in general, simple heuristics are not sufficient enough to accurately deal with complex document. In order to improve this, one possibility is to better take into account PDF format structure, as specified by Adobe (see PDF accessibility by Adobe), as soon as the file was properly generated. Another possibility comes from the computer vision community concerning document layout analysis (see, e.g., [25,26]). One advantage of the later solution is to allow one to consider any kind of document, including captured images of printed document (we refer to Section 5 for more comments).

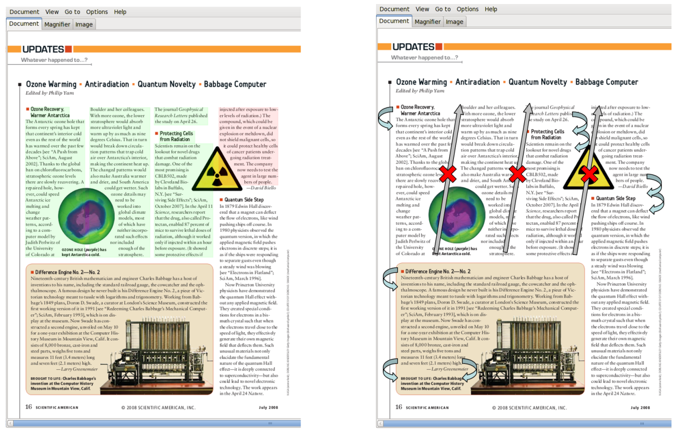
4 Experimental results with low vision patients

This section presents tests with 26 low vision patients. *Navisio* was evaluated according to two criterion's: reading performance and reading comfort.

4.1 Materials and methods

Subjects: 26 low vision patients (from 60 to 92 years old, average age is 78.2) participated in the tests. Their pathologies were mainly DMLA (about 80% of the patients). Their maximum reading speed, previously measured thanks to a French reading computer-based test ranged from 23 to 101 (average is 53.35) words/minute. Most patients had a weak knowledge of computer equipment but some often used electronic magnifiers.

Reading aid systems: Subjects used two reading aid systems: an electronic CCTV magnifier (*Clearview+*) and a computer with *Navisio* installed. Note that both systems do not work with the same input, and that this study is valid for documents which exist in printed and electronic version, such as newspapers.



(a) (b)

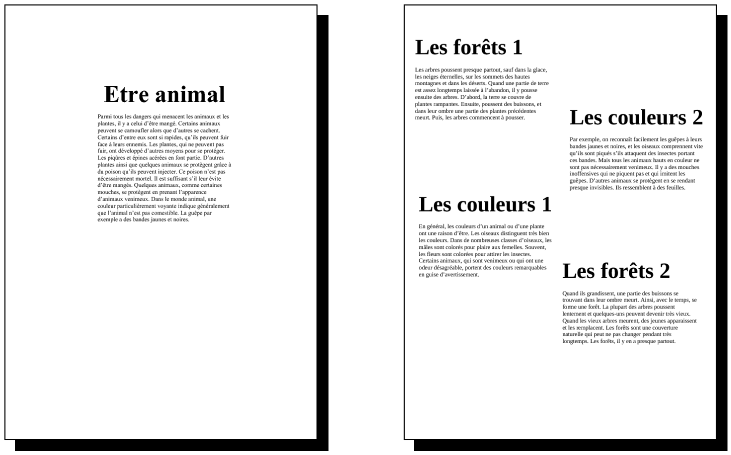
Fig. 6. Layout document analysis (a) As soon as a paragraph, defined by the layout analysis, is shown in the enhanced view, a color code will indicate it in the document view. (b) In general, our document layout analysis allows the patient to read continuously different paragraphs related thanks to heuristics. Thus, for example, paragraphs in the same column are shown continuously in the enhanced view as the patient scrolls down. More complex transition such as changing columns are not handled in this version.

Texts and documents: To estimate reading speed, one needs a database of calibrated texts since one cannot use twice the same text to compare two systems. In order to guarantee that different texts contained the same complexity and semantic information, we used the French standardized text database from [27]. In [27], reading speed was shown to be equivalent for 10 French texts for normal sighted people. These texts are left justified, and the selected font is Times New Roman, and they were matched in length (830±2 characters). In our experiments, we used them to compose two kinds of documents (simple and complex, see Figure 7). Electronic version is used with *Navisio* and a printed version is given for the magnifier. Proposed texts correspond to 0.5° of visual angle for a subject at 40cm from the monitor and titles correspond to 1.5°.

Measuring reading performance: Oral reading speed for a subject is measured for both simple and complex documents. If reading speed was considered as too slow by the orthoptist, only one standardized text was read in the complex document case.

During the reading phase, each misread word was marked. Right after the reading phase, three questions were asked to estimate the understanding of the subjects for each text.

When the test was finished, subject was asked to give a grade concerning the feeling of comfort for each tool.



(a) (b)

Fig. 7. Sample documents (a) Simple documents: One standardized text with a title is centered on the page (b) Complex document: Two standardized texts are splitted into 4 paragraphs and distributed on a page with titles.

Description of protocol: Protocol is divided into two sessions.

During the first session (about 30 minutes), the subjects learned how to use both tools and selected the optimal magnifying factor for the magnifier, as well as the best display parameters in the *Navisio* software. The distance to the screen was not fixed.

During the second session (about 30 minutes), the subject randomly read simple and complex documents with the magnifier and with *Navisio*. For a simple document, the subject read the title and the text as soon as the page is given. For a complex document, the subject had to read two or four titles and texts (out of the four texts proposed) in a random given order to force the patient to navigate in the document. Mistakes in the reading order were marked by the orthoptist. Reading speed was measured during that session.

4.2 Results

Results about reading speed, reading understanding, words misreading proportion and reading comfort are shown in Figure 8.

Figure 8 (a) is about reading speed measurements for simple and complex documents in low-vision patients. It shows an overall increase of reading speed by 18.5% for *Navisio* with simple documents (close to MyReader benefit results [23]) and 16.5% for complex documents. Variation is significant with a T-test for dependent samples in simple document (t=-5.09678, df=25, p=0.000029) and in complex document (t=-4.79425, df=25, p=0.000064).
Also, results show that reading a complex document takes 8% longer than reading a simple document with a CCTV magnifier and 11% longer with *Navisio*.

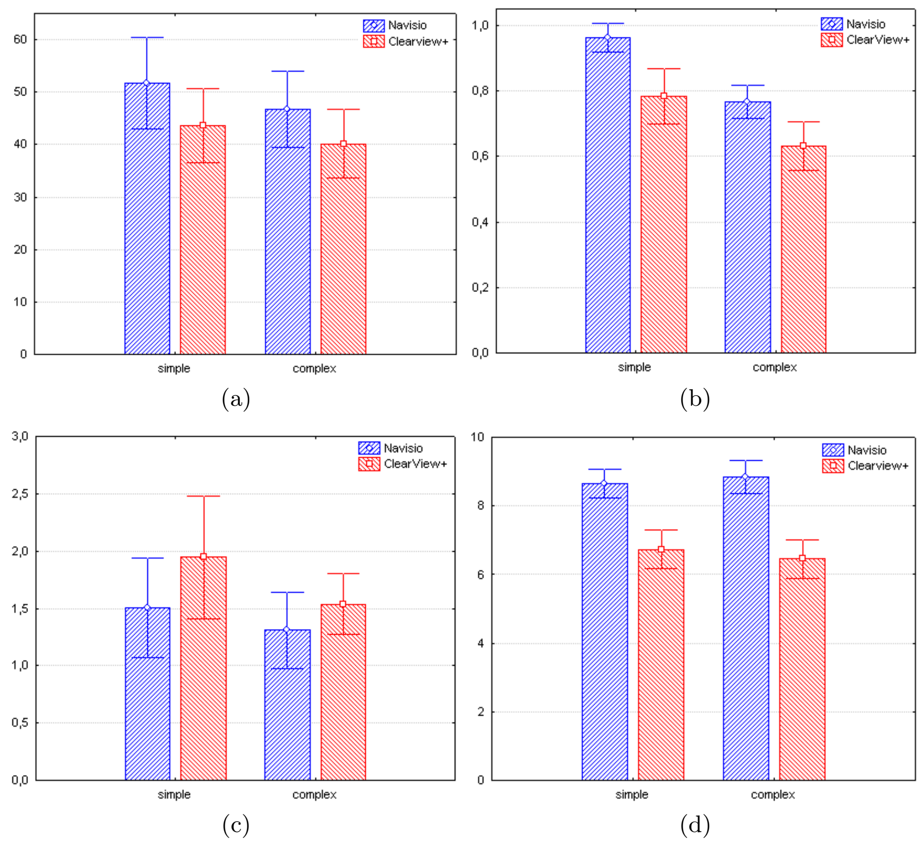


Fig. 8. Experimental results with low vision patients (a) reading speed (words/mn), (b) understanding evaluation (ratio of correct answers to the questionnaire), (c) words misreading (percentage), (d) reading comfort (average grade between 0 and 10). Bars are 95% confidence interval

It is likely that texts with more complex structures would have shown a higher reading speed difference and a better profit of *Navisio*'s main purpose: the facilitation of the local/global navigation.

Figures 8 (b) and 8 (c) show that *Navisio* brings also a meaningful advantage in terms of understanding (+22% for simple document and +23% for complex document) and reading mistakes (-23% for simple document and -15% for complex document). So, for both kinds of documents, *Navisio* increases reading performances. For understanding, variation is significant with a T-test for dependent samples in simple document (t=2.241040, df=25, p=0.034146) and in complex document (t=2.331032, df=25, p=0.028113). For reading mistakes, variation is significant with a T-test for dependent samples in simple document (t=-5.40062, df=25, p=0.000013) and in complex document (t=-5.12989, df=25, p=0.000027).

Figure 8 (d) shows the most significant difference between *Navisio* and the CCTV magnifier: the reading comfort. *Navisio* was given an average grade of 8.65/10 for the simple document and 8.85/10 for the complex document, while for the CCTV magnifier it was 6.73/10 respectively 6.46/10. Variation is significant with a T-test for dependent samples in simple document (t=-5.95238, df=25, p=0.000003) and in complex document (t=-6.70751, df=25, p=0.000001).

The reading comfort proposed by *Navisio* is its most important interest, especially for complex document reading.

Finally, when the patients were asked which tool they would prefer to use at home if they had the possibility to have the same printed and electronic document, 85% of the patients answered they would prefer *Navisio*. If we don't take into account patients who often use a CCTV magnifier, this percentage is about 96%.

Interestingly, *Navisio* was a really appreciated reading aid system, even by patients not used to navigate on a monitor with a mouse. These results prove the interest for such a high parameterizable electronic document reader with local/global navigation.

5 Conclusion

In this article, we described the new *Navisio* software which main goal is to help low vision patients read complex documents. The main feature is to enable a smooth navigation between a global document view and a local customizable view to read an electronic document (here a PDF file). We showed how the local view parameterization is related to recent psychophysical results on reading performance. *Navisio* has been evaluated with low vision patients and compared with a classical CCTV magnifier tool. Our tests revealed the efficiency of *Navisio* to read simple and complex electronic documents: Reading speed and comfort were significantly enhanced.

Of course, *Navisio* is intended to evolve and include more functionalities. Among forthcoming extensions that we consider, let's mention the addition of an audio support, further features to facilitate navigation and the possibility to select the RSVP in the enhanced mode.

Beside the realisation of this software, the goal was to integrate in a software existing and novel ideas to help low vision patients to read any kinds of electronic documents, and to have those ideas justified from the psychophysics point of view. The principles introduced here could be easily extended and applied to any kind of electronic documents, such as *ebooks* for example, as soon as devices allow the human/machine interactions.

A step further, the important evolution which would highly benefit from recent advances in the computer vision community, is the possibility to handle any kind of text, such as hand-written texts or texts captured by a camera (similarly to *myReader2*). The crucial step is to have a robust document layout analysis (see, e.g., [25,26]), in order to identify each component of a text, determine the logical structure of the paragraphs and perform optical character recognition

(OCR). Much progress has been achieved but, to our knowledge, having a fully robust approach remains an open question. Such a pre-processing was tested in this context of low vision (see [28]) but processing times and robustness remain an issue before integrating the OCR chain in a system (this is one weakness of MyReader). GPU-performance may help for processing times but new methods may also be required to improve robustness.

Finally, another challenging perspective which is also mentioned in [28], is to use an eyetracker system with high frequency performance in order to adapt the display in the enhanced view depending on the fixation. This could help to suppress the difficult mouse navigation task present in most of the reading aid tool (see [29] for normal vision). Real time text deformations could also be useful to move the text on optimal health zones of the retina, but this is still a very difficult problem to validate such feature from a psychophysical point of view.

Acknowledgements

Thank you to our colleagues from the Hospital La Timone in Marseille and particularly Fatiha Barouch as well as the patients who participated in the tests.

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